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Workspace Awareness in Collaborative Audio-Only Interaction with Diagrams

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ABSTRACT
Using an audio-only diagraming tool, sixteen pairs of sighted individuals collaborated in a workspace where they used sound as the only means to communicate with each other and to access and edit shared entity-relationship diagrams. We examined the effects of the means for delivering audio to such a workspace – using headphones or speakers – on pairs' workspace awareness. Results showed that patterns of workspace awareness information exchange changed when both the means for delivering audio and collaborators' choice of working style changed. The results highlighted the need to accommodate different working styles when designing awareness support in collaborative diagramming tools, and identified the types of awareness information that should be communicated to collaborators to match the dynamics of their interactions with and through diagrams.

ACM Classification Keywords
H.5.2 Information Interfaces and Presentation: Users Interfaces–Auditory (non-speech) feedback; H.5.3 Information Interfaces and Presentation: Group and Organisation Interfaces–Collaborative computing, Computer-supported cooperative work, Synchronous interaction

Author Keywords
Audio-only Collaboration, Workspace Awareness, Diagrams

INTRODUCTION
In order to collaborate efficiently, individuals need to both be able to communicate with one another, and to pick up clues from the environment to establish an understanding of who is around and how they are contributing to the shared activity [9]. This type of knowledge is often taken for granted in face-to-face interaction, but it is considered a significant challenge for both users and designers of computer-supported collaborative systems [2, 4]. A major research area emerged in CSCW concerned with this problem, adopting the term *awareness* to refer to collaborators' ability to construct knowledge about various aspects of their joint activity, and to use it to efficiently integrate interdependent activities. Gutwin and Greenberg [5] suggested that part of the solution to addressing the awareness problem in groupware design is to provide users with more information about their collaborators. But designers must carefully determine what information is most important and relevant at any given moment during a collaboration in order to avoid overloading users with too much information. Additionally, most support for awareness in collaborative systems rely on visual displays [6]. But there are many situations where visual displays can be inadequate for accessing information. For example, when users engage in multiple tasks that compete for visual attention, or for individuals who experience a situational or permanent visual impairment [10]. Auditory display could be an alternative and complimentary modality in such cases, and while previous research has shown its potential to support workspace awareness (e.g. [3, 1]), more studies are needed to understand the practicality of audio as a medium for conveying and supporting collaborative interaction. By focusing on audio-only collaborative interaction with diagrams, this paper presents a study that contributes to understanding the impact of auditory display on workspace awareness information exchange.

BACKGROUND

Audio in collaboration
Sound plays a primary role in communication, mediating not only verbal exchange, which is essential in collaboration, but also a variety of incidental events that contribute to enriching collaborators' awareness of the context of their interactions. In remote collaboration, auditory display of information has been shown to provide a usable and sociable space for interaction even in the absence of other modalities [8]. Researchers have learnt from the way in which people use incidental sounds, and used this knowledge to design and integrate auditory cues back in shared spaces. Such engineered sounds were found to support awareness and enrich the collaborative experience [3, 1, 16]. In co-located collaboration, audio has been used to augment visually-dominant collaborative displays (such as interactive boards, wall displays and tabletops) with auditory feedback that communicate information about users' actions and represent aspects of the shared workspace itself. The means for delivering audio in such multimodal contexts – through

headphones, individual or shared speakers – can impact levels of awareness as well as strategies for completing shared tasks [15, 11]. However, it remains unclear what this impact is on the exchange of workspace awareness information in audio-only collaboration.

Audio and workspace awareness

Gaining an awareness *of something* in a collaboration involves acts of monitoring both the shared space and co-present individuals, as well as displaying one's own activities to others. Competent collaborators typically adjust the levels of obtrusiveness in their monitoring of co-workers and explicitness in displaying their own actions to match the demands of the current task or state of the collaboration [7]. *Workspace awareness* is one particular type of awareness that refers to the ability to keep track of collaborators' interactions within a synchronously shared workspace. Gutwin and Greenberg [5] framework for workspace awareness describes what knowledge constitutes workspace awareness, which perceptual mechanisms are used to extra such knowledge from a shared workspace and how it benefits collaboration. One important characteristic of workspace awareness is its focus on collaborators' interaction within a defined space, in realtime, and with shared resources [4]. However, the potential of audio as a sole means for delivering and maintaining workspace awareness remains largely unexplored.

STUDY

To contribute to addressing these gaps, we aimed to examine how the means for delivering audio to an audio-only workspace impacts the exchange of workspace awareness information during collaborative diagram editing. In this study, pairs of participants worked together in an audio-only workspace to construct entity-relational (ER) diagrams [1] from a textual description using a shared audio-only diagramming tool. The workspace was such that participants could not see one another but could hear each other, and could not see the diagrams they worked on but access them through an audio-only interface. The tool we used to achieve this was based on Metatla *et al.*'s approach to the sonification of diagrams [14, 12] allowing participants to both explore and edit diagrams' content through sounds. We manipulated how the audio output resulting from participants' interactions with this tool was delivered to the shared workspace in a within-subjects experimental design. In a *Shared* condition, the audio output of each participant's interactions with the tool was delivered through speakers, rendering its auditory output present in the collaborative workspace, i.e. participants could hear both their interactions with the shared tool and their partners'. In a *Non-Shared* condition, the audio output of each participant's interactions was delivered through their own headphones, rendering the audio absent from the collaborative workspace, i.e. participants could hear themselves but not their partners' interactions with the shared tool.

[1] ER diagrams are used by system analysts and software engineers to model the conceptual structure of a system prior to its development and are particularly popular for modelling database systems.

Setup

We opted for a co-located collaborative setting in order to compare both shared and non-shared audio setups under the same conditions[2]. Pairs sat facing each other and had each a keyboard to interact with the audio-only tool and a set of computer speakers or headphones to use in the Shared and Non-shared conditions respectively (see Figure 1). The keyboard, speakers and headphones were connected to two computers, one for each participant with one of those acting as a server and linking the pair to a shared diagram. An opaque board was placed between the two participants to eliminate any form of visual communication (body language, facial expressions, etc.). Participants could only hear each other's audio output in the Shared condition, but they were able to converse comfortably with one another in both conditions.

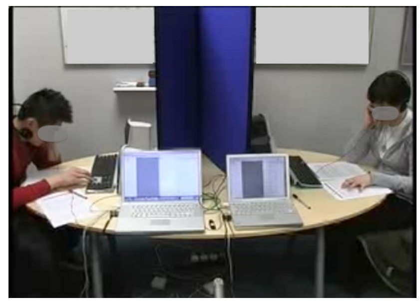

Figure 1. Experimental setup

Procedure

Participants were introduced to the basics of ER modelling and to the audio-only collaborative tool. Features of the tool and its auditory display were thoroughly demonstrated until the participants felt comfortable using it. They were then presented with a sample ER diagram and a textual description – similar to those used in the testing part – and were given time to use the tool to construct various parts of the diagram while being closely assisted by the experimenter. The training part lasted for up to thirty minutes. Once familiar with the tool, they were asked to perform the experimental task.

Collaborative task

Participants were asked to constructed two diagrams, one at a time, under each of the two experimental conditions; the order of the conditions was randomised across the sixteen pairs to cancel out learning effects. The testing part lasted for up to an hour. At the start of each test, an initial diagram was loaded onto the tool and participants were given a textual description containing information about how the diagram could be completed. The initial diagram consisted of a subset of the elements shown in Figure 2. Participants were instructed to consult the textual descriptions and to complete the diagram as they see fit. They were informed that they had complementary information on each description and therefore needed to

[2] A co-located setup also allows for a technically simple realtime provision of shared audio for the purposes of this study; i.e. using speakers rather networked transmission of shared audio, which can introduce latency issues that might interfere with the analysis of workspace awareness exchange, and hence deviating the focus of the present study.

Element	Supplied	Requested
1 Location	Where I am	Where are you?
2 Action	What I did	What did you do?
3 Action	What I'm doing	What are you doing?
4 Intention	What I will do next	What will you do next?
5 Changes/Completion	I'm done	Did you finish?

Table 1. Workspace awareness elements used in the study

consult with one another. They were given no time limit to complete the diagram, and were free to decide which information to include from the description and which to omit or delete from the provided initial diagram. Figure 2 shows an example of the typical complexity that the finished diagrams reached.

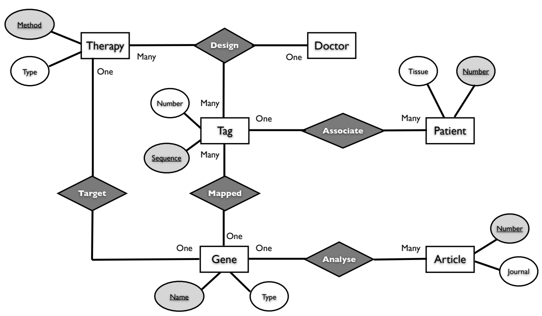

Figure 2. Example of an ER diagram.

Participants

Thirty-two sighted individuals were recruited for this study. Twelve participants were undergraduates, twelve were studying for a Masters, seven at various PhD levels and one participant at a post-doctoral level. Twenty-four were male and eight were female. This made up a total of sixteen pairs who knew each other. All participants were from the computer science or electronic engineering disciplines and had varying knowledge of ER diagrams ranging from very low to very high. Each participant received a cash incentive for their participation.

Data Gathering, Transcription and Coding

We transcribed the conversations between participants in a pair and used Gutwin and Greenberg's framework for workspace awareness (WA) [5] to develop a coding scheme identifying occurrences of WA elements in the transcripts. Table 1 shows the five elements of WA information that we focused on in this scheme given the nature of our experimental setup. These are: information about location within the shared workspace (in this case this refers to which diagram element a participant is working on); past and current editing and navigation actions; intention about future actions; and information about an action's completion status. We further divided WA information exchange into *Supplied* and *Requested* types, where the supplied type refers to information provided by a participant to their partner without the latter having asked for it, and the requested type refers to instances where a participant explicitly asks their partner for information regarding their actions, intentions or location. Two independent coders used the developed coding scheme to code video transcripts from two pairs' collaborations. We performed an interrater reliability analysis using the Kappa statistic to determine consistency among raters. This revealed high levels of reliability Kappa = 0.93 ($p<0.01$).

RESULTS

All pairs completed the construction of two ER diagrams under each experimental condition using the provided tool. Data from one pair was lost due to a system failure and was thus excluded from the analysis. We used Wilcoxon Sign Ranks tests with Bonferroni adjustments to determine significance within the captured data. The tests confirmed that overall participants exchanged significantly more WA information in the Non-Shared condition than they did in the Shared condition ($W=25.5$, $p<0.005$). Participants supplied significantly more WA information to each other than they requested from one another in both conditions (70% supplied versus 30% requested in the Shared conditions; $W=79.5$, $p<0.01$, and 75% supplied versus 25% requested in the Non-Shared condition; $W=5$, $p<0.01$). A separate comparison of the supplied and requested types of WA information across the two conditions revealed that the supplied type of exchanges were significantly higher in the Non-Shared condition ($W=23$, $p<0.005$), but differences between the requested type of exchanges across the two conditions were not statistically significant ($W=106.5$). Comparing the occurrences of each of the five elements of the supplied type across the two conditions revealed that exchanges of three out of the five elements were significantly higher in the Non-Shared condition; pairs supplied significantly more information of type *"What I Did"* ($W=25.5$, $p<0.01$), *"What I Am Doing"* ($W=81$, $p<0.05$) and what we refer to as *"Supplied Completion Status"*[3] ($W=15$, $p<0.01$) when audio was delivered through headphones.

Working Styles

An analysis of working styles based on Metatla *et al.*'s analysis of group interaction patterns [13] revealed that most pairs used a parallel working style as a dominant style in the Non-Shared condition, but worked sequentially and/or in parallel in the Shared condition. In particular, the proportion of overlapping interaction times were significantly higher in the Non-Shared condition (42.56% vs 26.22% in the Shared condition; $t=2.841$, $p=0.013$), but this result changed when pairs were grouped on the basis of their dominant working style in the Shared condition. For pairs classified as *Sequential*, the proportion of overlapping interaction was significantly higher in the Non-Shared condition than it was in the Shared condition (43.29% versus 8.03%; $t=8.219$ at $p<0.001$). For pairs classified as *Parallel*, the difference of overlapping interaction times between the two conditions was not statistically significant (42.22% Non-Shared versus 42.11% Shared; $t=0.2$, $p=0.98$). The following reports on the results of post-hoc analyses as independently applied to each working style group.

Results for Parallel Pairs

A total of eight pairs were classified as *Parallel* based on their dominant collaborative working style in the Shared condition. Parallel pairs exchanged significantly more WA information in the Non-Shared condition than they did in the Shared condition

[3] This refer to element number of 5 in Table1.

(W=27.5 for N=16, p<0.02). They supplied more WA information to each other than they requested from one another in both conditions, but the difference was only statistically significant in the Non-Shared condition (58% supplied versus 42% requested in Shared, 67% supplied versus 33% requested in Non-Shared; W=5 for N=15, p<0.01). A separate comparison of the supplied and requested types of WA information across the two conditions revealed that parallel pairs supplied significantly more WA information in the Non-Shared condition than they did in the Shared condition (W=16.5 for N=16, p<0.01) but differences between the requested types across the two conditions were not statistically significant. Comparing the occurrences of each of the five elements of the supplied types across the two conditions revealed that exchanges of two out of five elements were significantly higher in the Non-Shared condition; *"What I Did"*(W=12.5 for N=14, p<0.01), and *"Supplied Completion Status"* (W=7 for N=10, p<0.01).

Results for Sequential Pairs

Seven pairs were classified as *Sequential* based on their dominant collaborative working style in the Shared condition. Sequential pairs exchanged significantly more WA information in the Non-Shared condition than they did in the Shared condition (W=3 for N=14, p<0.01). Sequential pairs supplied more WA information to each other than they requested from one another in both conditions (84% vs 16% in Shared, and 82% versus 18% in Non-Shared). The proportion of WA information that was supplied and requested in the Non-Shared condition was significantly higher than that in the Shared condition (W=1 for N=13, p<0.01 for the supplied; and W=8 for N=12, p<0.02 for the requested). In particular, sequential pairs supplied significantly more WA information of type *"What I Did"* (W=4 for N=14, p<0.01), *"What I Am Doing"* (W=17 for N=13, p<0.05) and *"Supplied Completion Status"* (W=2 for N=10, p<0.01), and requested significantly more WA information of type *"What Did You Do"* (W=2.5 for N=12, p<0.01) in the Non-shared condition. Differences in the proportions of the remaining elements were not statistically significant.

Parallel vs. Sequential Pairs

A Mann-Whitney test revealed that there was no significant difference in the overall amount of WA information exchanged between parallel and between sequential pairs in the Shared condition. However, comparing the supplied and requested types of exchange separately in this condition revealed that parallel pairs requested significantly more WA information from one another than the sequential pairs (U=58.5, p<0.05), particularly of type *"What Did You Do"* (U=56.5 p<0.02). In the Non-Shared condition, sequential pairs exchanged significantly more WA information than the parallel pairs (U=50, p<0.02). Comparing the supplied and requested types separately in this condition revealed that this difference was significant for the supplied type (U=38, p<0.02) but not the for requested type (U=102.5). In particular, sequential pairs supplied significantly more WA information of the type *"What I Will Do"* (U=40.5, p<0.02). No significant difference was found for the remaining WA elements.

DISCUSSION

The study presented in this paper examined how WA information was exchanged between pairs of individuals while collaborating to design entity-relationship diagrams in an audio-only workspace. An audio-only collaborative workspace where sound is present through speakers made information about partners' diagramming activity and progress readily available, but the use of this information varied depending on the working style. Particularly, the loose character of parallel pairs' collaborations often meant that participants felt a greater need to find out about each other's past actions and frequently supplied each other with information in the form of updates about what has happened. On the other hand, sequential pairs' collaborations were focused, and information was often supplied in the form of descriptions about what was currently happening or what was about to happen in the immediate future. The coding scheme that we used captured instances in the collaborations where participants explicitly exchanged information pertaining to workspace awareness. This provided a means for establishing which elements of workspace awareness information were used during the collaborations and for quantifying such information. The results confirmed that delivering audio through headphones to an audio-only workspace increased participants exchange of workspace awareness information. Participants supplied significantly more information to each other than they requested from one another, but examining the details of such exchange revealed that this significance was in supplying WA information of types *What I Did* (past actions), *What I am Doing* (current actions) and *Completion Status* (activity level). However, when considering each working style group independently, our analysis revealed differences in the details of these exchanges:

- Parallel pairs supplied as much WA information to each other as they requested from one another when audio was delivered through speakers. On the other hand, sequential pairs supplied significantly more information to each other than they requested from one another in both conditions.
- When audio was delivered through headphones, parallel pairs supplied significantly more WA information of type *What I Did* (past actions), whereas sequential pairs supplied significantly more WA information of type *What I Am Doing* (current actions) and requested significantly more WA information of type *What Did You Do* (partner's past actions).
- When compared against each other, sequential pairs were found to supply significantly more WA information of type *What I Will Do* (intentions) than parallel pairs when audio was delivered through headphones.

CONCLUSION

Awareness of other people's activity is an important part of shared-workspace collaboration. Gutwin and Greenberg [5] suggested that part of the solution to addressing the awareness problem in groupware design is to provide users with more information about their collaborators. But designers must carefully determine what information is most important at any given moment in a collaboration.

Awareness has typically been supported using visual displays. But there are many situations where attending to a visual display can be difficult, for example due to the type or context of activities users engage in or the type of devices they use in such activities, which may have limited screen space for displaying information. Using audio as a means for providing awareness information, for instance by providing audio representations of actions on these devices, can overcome these limitations.

The study presented in this paper provides new empirical evidence about the use of audio as means for gaining awareness in a shared workspace. In particular, the study aimed to examine the impact of the means for delivering audio to an audio-only workspace on the exchange of workspace awareness information in the context of diagram editing collaborative activities. The results showed that varying the means for delivering audio to such a workspace had an impact on which workspace awareness information was exchanged between partners, and that this observed impact was also dependent on the working style they chose to employ.

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